Food Measure (2017) 11:1035–1044
DOI 10.1007/s11694-017-9479-4

ORIGINAL PAPER

Chemical composition, amino acid and fatty acid contents, and mineral concentrations of European beaver (*Castor fiber* L.) meat

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Received: 10 September 2016 / Accepted: 17 January 2017 / Published online: 2 February 2017

Abstract The present investigation was designed to determine the meat nutritional profile of European beaver (*Castor fiber* L.). The proximate composition, energy value, amino acids composition, chemical scores for indispensable amino acids, fatty acids composition and mineral concentrations were determined. In 100 g of meat the content for moisture ranged from 75.42 to 77.32 g, for protein from 20.21 to 22.33 g, for fat from 0.66 to 2.44 and for ash from 1.12 to 1.24 g. The Nutritional Quality Index for muscle protein was 9. The indispensable amino acids (IAA) at the highest content were lysine and leucine (1.85 and 1.65 g 100 g^{-1}). The average percentage of IAA was 45% and their chemical scores amounted to more than 100. The total percentages of trans-, saturated (SFA), mono, and polyunsaturated (PUFA) fatty acids were 2.25, 32.25, 18.83 and 49.08%. The ratio of PUFA/SFA and n-6/n-3 PUFA were 1.56 and 5.58. The cholesterol content averaged 55.10 mg 100 g^{-1}. The muscle tissue of beavers contained favourable amount of minerals, particularly Fe and heme Fe (64.49 and 45.60 mg kg^{-1}), Zn and Cu (45.07 and 0.98 mg kg^{-1}), as well a low level of Na (461.9 mg kg^{-1}). Summing up, beavers are a valuable nutritional meat source with a desirable chemical composition and a low calorific value and can constitute a healthy alternative food as advantageous for human health and coherent with diet recommendations.

Keywords European beaver · Meat · Nutritional profile · Amino acids · Fatty acids · Minerals

Introduction

Since ancient times wild animals have been associated closely with human food production. In history, certain wild mammal species have provided humans with opportunities for domestication and other species, even though never domesticated, can be used by humans to provide wild ingathering [1]. In the European Union, the main game meats are produce in particular in the traditional countries located in Central Europe: Poland, Austria, Hungary, Slovenia and the Czech Republic; while the large numbers of game (farmed as well wild) hunted in Germany and France are consumed locally. Other European producing countries are England and Scotland for small and big game, in that order, and Spain for red deer [2].

The European beaver (*Castor fiber* Linneaus 1758) is the largest herbivorous rodent in Poland. The sexual maturity animals reach at the age of at least 18 months, and reproductive capacity at the age of 3–4 years, exceptionally at 2 years [3]. Body length of a beaver may reach 1 m, and body weight of an adult varies from 9 to 30 kg [4], and the carcass of an adult animal can provide over 5.5 kg of meat [5]. Populations of European beavers are now established in most countries in Europe, or even grow higher from year to year [6]. The population of beavers in Poland increased considerably from 24,400 individuals in 2000 to above 100,000 animals in 2014 [7]. The density of beaver sites is determined by the availability of food, hydrological conditions and human pressure. In Poland site density ranges from 10 up to 72 per 100 km^2, with a single family accounting on average 3.7 beavers [3, 8].

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Although beaver is currently not considered as a consumptive animal in Poland, beaver is classified as a game species in a few European countries (Belarus, Estonia, Lithuania, Latvia, Norway, and Sweden) as well as in Canada and Russia [9]. As a result of damages include tree girdles, grassland flooding, arable crop damages [10], as well as production losses in fisheries, physical destruction at aquaculture facilities and costs of implementing damage prevention methods, the growing beaver population needs to be controlled [11]. In addition to the human factor (poaching, car collisions), the size of local population of beaver in Poland may be limited only by the pressure of large predators such as wolf and lynx [3]. Furthermore, by reason of the considerable increase in the number of beavers in Central and Eastern Europe, as well as development of beaver farm breeding, wider consumption and sustainable hunting as a management tool for beaver population is highly demanded [12]. According to regulations of the Polish Ministry of Environment from October 2014 (The Official Journal, Pos. 1348, 7.10.2014), beavers were either strictly or partially protected. However, beavers could be culled with local administrative (voivodship level) permission, e.g. in 2014 almost 4 500 animals were shot [7].

Nowadays, consumers are increasingly concerned about venison. Meat from hunting animals has always been attractive to consumers due to its special flavour [13]. The natural forage of wild animals rich in herbs, minerals and other components has a favourable effect on the nutritional and functional value of meat [14]. Moreover, beaver meat has been recognized as a perfect raw material [15], free from growth stimulators, antibiotics, hormones and other additives [5], with good technological properties [16]. Although the market for game products in recent years is very restricted, and dependent on the hunting season and the culling quotas, wild meat provides a niche in the contemporary food market [17–19]. Currently, the meat quality concept has become dynamic and includes eating and technological quality, nutritional value and safety. Thus meat diversification can be considered as an opportunity to meet the changes in consumer needs [12].

Therefore, the objective of this study was to determine the proximate composition, energy value, amino acid and fatty acid compositions and mineral concentrations of meat of European beaver (*C. fiber* L.) taking into account the actual dietary recommendations for protein and fats.

Materials and methods

Animals and samples

The research material included six males of European beaver. In Poland, beaver hunting is allowed from the first of October until the middle of March. The number of animals available for research was relatively low because beavers are protected and exactly six animals could have been hunted under permission of the Regional Director for Environmental in Lublin (Ref. No. WPN.6401.32.2015.JR). Moreover, the 'reduction' principle for more ethical use of animals in research was adopted. The animals were shot between February, 25 and March 15, 2015, by authorised hunters in two neighbouring State forest districts inside Lublin voivode. The estimated age of animals ranged between 10 and 32 months. Culled animals were weighted, bled, skinned and eviscerated. The mean body weight averaged 11.817 kg (±5.438 kg). Mean carcass weight of beavers after chilling was 5.856 ± 2.549 kg and dressing percentage was 50.60% (±1.29%). The carcass and inner organs were examined by "trained" hunters upon evisceration in compliance with provisions of Regulation 853/2004 [20]. During the examination no anomalies or hazards were identified. Eviscerated carcasses were transported to laboratory without any undue delay (within half an hour to maximum three hours after killing) in line with the highest available hygienic standards. From thighs the *musculus semimembranosus* (SM) were collected and stored refrigerated in darkness at 4 °C. Samples for all analysis were taken within 48 h *post mortem*. The analytical procedures were followed by trimming the visible adipose and connective tissue, which were then carefully separated and discarded. Duplicate measurements per sample were taken for analysis.

Proximate composition determination

The moisture content was determined according to PN-ISO 1442:2000 [21]; total ash in compliance with PN-ISO 936:2000 [22]; crude protein content (N × 6.25) according to PN-A-04018:1975/Az3:2002 [22]; total fat content in line with PN-ISO 1444:2000 [24]. The energetic value of lean muscle tissue expressed as kJ per 100 g^{-1} was calculated using energy equivalents, 16.76 kJ for protein, and 37.66 kJ for fat. The Hansen's Nutritional Quality Index (NQI) [25] was calculated for the protein and fat using the reference intakes for energy and selected nutrient [26].

Heme iron concentration

Heme iron content was estimated by multiplying the hematin quantity determined according to the Hornsey's [27] method using a Varian Cary 300 Bio spectrophotometer (Varian Australia PTY, Ltd.) at 640 nm wavelength by factor 0.0882 µg iron/µg hematin [28].

Fatty acid composition and cholesterol content

Fatty acid methyl esters (FAMEs) and cholesterol content were analysed following fat extraction according to Folch et al. [29]. Further steps were carried out according to PN-EN ISO 12966-2:2011 [30] and PN-EN ISO 5508:1996 [31]. FAMEs were separated in a Varian CG 3900 (Walnut Creek, USA) gas chromatograph with a flame ionization detector (FID). A CP 7420 capillary column was used (Agilent Technologies, USA), 100 m in length, inner diameter 0.25 mm, film thickness 0.25 µm. The analysis was carried out in increasing temperature conditions. The initial temperature of the oven was 50 °C, and the final temperature was 260 °C. The temperature of the injector and the detector was 270 °C, the carrier gas (hydrogen) flow rate 2 mL/min, the size of the injected samples 1 µL, and the split ratio 1:50. Identification of FAMEs was based on retention times corresponding to reference mixtures (Supelco Inc., Bellefonte, PA, USA). Fatty acids were expressed as percentage (%) of the sum of detected FAME using Star GC Workstation Version 5.5. software (Varian Inc., Walnut Creek, USA). The following ratios were calculated SFA/PUFA and n-6/n-3 PUFA.

The total cholesterol content (mg 100 g^{-1}) was determined using internal standard (5-α-cholestan) and VF-5ms capillary column, by means of Varian CG 3900 (Walnut Creek, USA) gas chromatograph and Star GC Workstation Version 5.5. software (Varian Inc., Walnut Creek, USA). The analysis was carried out in condition of mutable temperature. The initial oven temperature was 250 °C, and holding time 2 min. The rate of temperature rise was 3 °C min^{-1}, and total time of analysis 16 min. Other parameters were as follows: temperature of the injector and the detector was 300 °C, the carrier gas (hydrogen) flow rate 2 ml/min, the size of the injected samples 1 µL, and the split ratio 1:10.

Amino acid analysis

The contents of amino acids after hydrolysis were carried out using an automatic amino acid analyzer AAA 400 (Ingos Ltd. Czech Republik) equipped with an Ostion LG ANB ion-exchange column. The sample volume of 100 µL was injected into analyzer. Amino acids were separated by stepwise gradient elution using a citrate buffer-system (pH 2.6–7.9) and post-column derivatization with (amine-)ninhydrin reagent followed by a photometric detector (at 570 and 440 nm) was used for determination of amino acids, expressed as g 100 g^{-1} of wet mass. The chemical score of indispensable amino acid (IAA) was calculated with respect to the FAO recommended amino acid scoring patterns (mg g^{-1} protein requirement) for adults [32].

Mineral analysis

The concentration of eight minerals (K, Na, Ca, Mg, Zn, Fe, Mn, Cu) was determined by means of the flame atomic absorption spectrometry (FAAS; air-acetylene flame) using a Varian Spectra 240FS spectrometer. The samples (1 g) of lean muscle tissue were wet-digested with 9 mL concentrated nitric acid using the microwave oven MarsXpress (CEM Corporation, Matthews, NC, USA). Digested samples were transferred to polypropylene tubes and diluted to 25 mL with ultrapure water. A blank digest (9 mL HNO_3) was carried out in the same way. For sodium and potassium levels determining, a solution of caesium chloride was added as a deionised buffer to all of the samples and standards. The lanthanum chloride solution was used as a correction buffer to determine calcium and potassium. During the analysis deuterium background correction was used and limits of quantification (LOQ) and detection (LOD) were taken into account. During the analysis the following detection limits (LOD) were taken into account, for Na, Mn, Cu and Zn 0.01 mg kg^{-1}; for K 0.04 mg kg^{-1}, for Fe 0.09 mg kg^{-1}, for Ca 0.22 mg kg^{-1}, and for Mg 0.47 mg kg^{-1}. The method accuracy was evaluated by means of trace metals determined in the DORM-3 and 1546 C Standard Reference Material. Analyses were performed in duplicate and the content of minerals was expressed in mg kg^{-1} wet mass.

Statistical analysis

The analyses were performed using the Data analysis package of Microsoft® Excel® 2010 (© 2010 Microsoft Corporation). In tables the descriptive statistics including mean, standard deviation, minimum and maximum values were given.

Results and discussion

Proximate composition

The descriptive statistics of proximate composition of *semimembranosus* muscle are reported in Table 1. The protein and ash contents in the present research were close to those reported for wild sexually mature beavers by Jankowska et al. [5] (thigh 21.7 and 1.29%, loin 21.84 and 1.31%) and by Żochowska-Kujawska et al. [15] for meat obtained from 5 cuts: thigh, flank, loin, shoulder and tail (21.44 and 1.08%). Contrary, Korzeniowski et al. [33] found higher values (22.09 and 1.33 g 100 g^{-1}) for meat (as an average of the three elements: thigh, loin and tail) from farmed beavers aged between 7 and 19 years. Similar content of protein and ash to present results was also stated by Razmaitė et al. [12] in thigh of wild

Table 1 Proximate composition of beaver *semimembranosus* (n = 6)

Components and indices	Mean	SD	Min.	Max.
Moisture (g 100 g^{-1})	76.07	0.55	75.42	77.32
Protein (g 100 g^{-1})	21.57	0.74	20.21	22.33
Fat (g 100 g^{-1})	1.14	0.56	0.66	2.44
Ash (g 100 g^{-1})	1.19	0.05	1.12	1.24
Heme iron (mg 100 g^{-1})	4.61	0.73	2.96	6.59
Moisture: protein ratio	3.53	0.15	3.38	3.77
Energy (kJ 100 g^{-1})	404	14.9	379	430
NQI for protein	8.97	0.47	7.89	9.40
NQI for fat	0.33	0.15	0.20	0.68

NQI nutritional quality index

beavers hunted in Lithuania (21.6 and 1.09%), and Strazdina et al. [34] for *biceps femoris* (21.39 and 1.13%) and *longissimus lumborum* (21.81 and 1.20%) from Latvian animals. The stated differences in literature could be connected with different time of hunting or different condition of beaver's habitat in mentioned countries of Central Europe. In other investigation Korzeniowski et al. [35] did not find any influence of beaver weight (<10 kg, 10–20 kg, >20 kg) and sex (male vs. female) on the chemical composition of meat from thigh, rump and tail.

The fat content in present study was higher compared to Lithuanian research (0.51%) [12], but considerably lower than Latvian (3.63–4.29%) [34, 36], and Polish (3.8–5.1%) [5, 15, 35] investigations included sexually mature wild beavers. The highest fat content (5.80 g 100 g^{-1}) reported Korzeniowski et al. [33] for meat from farmed beavers aged between 7 and 19 years and weighing between 15.5 and 20.8 kg. Although, no additional information about age or weight of beavers from Lithuania and Latvia were reported, it is well known that the lipids content in different tissues depends on the composition of diet and dietary habits of beavers [37], as well as season [12].

In present study the energy value was between 379 and 430 kJ 100 g^{-1}. Higher energy of beaver meat compared to our results reported Korzeniowski et al. [35] for wild males hunted in autumn (thigh 492 kJ 100 g^{-1}, rump 516 kJ 100 g^{-1}), as well as Jankowska et al. [5] for sexually mature females and males (thigh 510.3 kJ 100 g^{-1}, loin 522.2 kJ 100 g^{-1}). However, these differences might be explained by a higher fat content related to sex, hunting season and the availability of the food resources.

Table 2 Amino acids composition (g 100 g^{-1} of fresh weight) of beaver *semimembranosus* (n = 6)

Amino acid	Mean	SD	Min.	Max.
Alanine	1.11	0.06	1.05	1.19
Arginine	1.17	0.08	1.08	1.25
Aspartic acid	1.87	0.12	1.74	2.03
Glutamine acid	3.49	0.19	3.29	3.76
Glycine	0.86	0.05	0.81	0.92
Proline	0.75	0.03	0.72	0.79
Serine	0.81	0.05	0.76	0.88
Tyrosine	0.68	0.04	0.63	0.75
Indispensible Amino Acids				
Histidine	0.83	0.06	0.77	0.92
Isoleucine	0.89	0.05	0.82	0.96
Leucine	1.65	0.09	1.55	1.80
Lysine	1.85	0.11	1.76	2.03
Methionine	0.53	0.07	0.42	0.61
Phenylalanine	0.83	0.04	0.79	0.90
Threonine	0.96	0.04	0.92	1.01
Tryptophan	0.31	0.04	0.25	0.36
Valine	0.94	0.08	0.83	1.04
IAA	8.78	0.43	8.36	9.41
Total AA	19.53	0.98	18.55	20.92
IAA (%)	45.00	0.19	44.65	45.22

AA amino acids; *IAA* indispensible amino acids

Amino acids

The dietary protein should be considered as a source of amino acids as individual nutrients. The composition of amino acid (AA) profile of beaver *semimembranosus* muscle is shown in Table 2. The indispensable amino acids at the highest content were lysine (1.85 g 100 g^{-1}) and leucine (1.65 g 100 g^{-1}), and within other (non-essential) AA glutamine acid and aspartic acid (3.49 and 1.87 g 100 g^{-1}). The average percentage of indispensable amino acids was 45.00%. Values of particular AA concentration were generally within the range given by Razmaite et al. [12] for thigh of Lithuanian beaver and Strazdina el al [36]. for *longissimus lumborum* of Latvian beaver. However, a higher content of glutamine acid, lysine and threonine but lower of alanine, arginine, histidine and isoleucine was stated in present study compared to results found by Razmaitė et al. [12] (3.30, 1.77, 0.90, 1.29, 1.31, 1.10 and 1.30 g 100 g^{-1}, respectively) and Strazdina el al [36]. (2.95, 1.71, 0.08, 1.36, 1.42, 1.00 and 1.09 g 100 g^{-1}, respectively). Żochowska-Kujawska et al. [15] for meat (from 5 cuts) of sexually mature beavers hunted from January to February in the Western Pomeranian district in Poland also reported similar content of lysine and tryptophan (1.97 and 0.29 g 100 g^{-1})

but lower of tyrosine (0.02 g 100 g^{-1}) compared to those found in this study.

The evaluation of the nutritional value of proteins should be made from amino acid data in comparison to requirements. The amino acids content in protein of beaver muscle tissue and their chemical score are shown in Table 3. Taking into account the latest recommended amino acid scoring patterns for adults (mg/g protein requirement) [32] all calculated average chemical scores of IAA amounted to more than 100. Razmaitė et al. [12] reported similar scores for threonine, valine, leucine and lysine, while Strazdina et al. [34] for methionine, valine, leucine and lysine compared to present study. Cited authors obtained higher scores for isoleucine (170–210%) and histidine (313–339%) than our investigation, however, their calculations were based on former FAO references.

Fatty acids

The fatty acid composition (% of total FAME) of intramuscular lipids from beaver semimembranosus is shown in Table 4. The linoleic acid (LA, C18:2 n-6) was dominant, accounting for over one-third of all of determined acids. The main acids within SFA's were palmitic and stearic (16.74 and 9.53%), while among MUFA's was oleic acid (10.52%). In addition to LA within PUFA's the high content of α-linolenic acid (ALA) was determined (6.16%). The total percentages of TFA, SFA, MUFA and PUFA in the present study in beaver skeletal muscle were as follow 2.25, 32.25, 18.83 and 49.08%. The ratios of PUFA/SFA and n-6/n-3 were 1.56 and 5.58, respectively. The cholesterol content in 100 g of beaver muscle tissue was 55.10 mg.

Comparable content of SFA (33.00%) to present study found Razmaitė et al. [12] in lipids from thigh of beaver, however, with a higher share of palmitic acid (23.05%) but lower percentage of stearic acid (6.77%). In addition, lipids from thigh of Lithuanian beaver contained a lower content of total PUFA and LA (41.58 and 22.66%) and a higher content of total MUFA and oleic acid (25.42 and 22.28%) compared to present study. Also Strazdina et al. [34] for *biceps femoris* of Latvian beavers reported different percentages of fatty acids, i.e. a higher content of oleic and α-linolenic (15.02 and 17.86%), but a lower content of linoleic acid (18.83%) and as a consequence a lower n-6/n-3 ratio (1.26) in comparison with present investigation. As well Razmaitė et al. [12] reported a lower n-6/n-3 ratio (2.12) for thigh of Lithuanian beavers, while

Table 4 Fatty acids methyl esters composition (% of total FAME) and cholesterol content of beaver *semimembranosus* (n = 6)

Fatty acid methyl ester	Mean	SD	Min.	Max.
C12:0	0.12	0.09	0.05	0.28
C14:0	0.77	0.21	0.54	1.03
C16:0	16.74	1.94	13.72	19.35
C18:0	9.53	1.85	6.65	12.18
C18:1n-9	10.52	4.53	7.29	19.53
C18:2 n-6, LA	36.10	5.69	27.55	42.50
C18:3 n-3, ALA	6.16	1.86	3.27	8.68
CLA	0.23	0.03	0.20	0.27
SFA	32.25	3.95	26.96	39.07
MUFA	18.83	5.06	14.57	28.67
PUFA	49.08	6.77	39.62	56.00
n-3	7.62	1.61	4.93	9.42
n-6	40.43	6.64	29.13	46.09
n-6/n-3	5.58	1.42	3.09	7.34
LA/ALA	6.36	2.04	3.17	9.47
PUFA/SFA	1.56	0.36	1.08	2.08
TFA	2.25	0.45	1.64	2.69
Cholesterol (mg 100 g^{-1})	55.10	5.81	47.49	64.46

CLA conjugated linoleic acid; *SFA* saturated fatty acids; *MUFA* monounsaturated fatty acids; *PUFA* polyunsaturated fatty acids; *TFA* trans fatty acids

Table 3 Amino acids content (mg g^{-1} protein) of beaver *semimembranosus* (n = 6) and recommended amino acid scoring patterns for adults [30]

Amino acid	Mean	SD	Min	Max	Recommended scoring pattern mg/g protein requirement	Chemical score of IAA (%)
Histidine	39	2.0	36	41	16	244 (223 ÷ 259)
Isoleucine	41	2.7	38	45	30	138 (126 ÷ 148)
Leucine	78	5.2	72	83	61	127 (118 ÷ 136)
Lysine	87	5.8	81	93	48	181 (168 ÷ 193)
Methionine	25	3.9	19	30	23	108 (82 ÷ 129)
AAA	71	4.7	66	76	41	173 (162 ÷ 186)
Threonine	45	2.6	42	49	25	179 (169 ÷ 194)
Tryptophan	14	1.9	12	18	6.6	218 (175 ÷ 265)
Valine	44	4.3	39	49	40	110 (96 ÷ 121)

AAA aromatic amino acids (Phe + Tyr); *IAA* indispensible amino acids; Chemical score of IAA, % = 100× [(mg of indispensable amino acid in 1 g of the dietary protein)/(mg of the same dietary indispensable amino acid in 1 g of the reference protein)]

Żochowska-Kujawska et al. [15] for meat of Polish beavers (>1.5-year old) found a very similar value (5.34) to our results.

Similarly to present findings, Jankowska et al. [5] reported a lower proportion of MUFA and higher of PUFA in lipids from loin (20.35 and 47.97%) and thigh (21.13 and 53.13%) of sexually mature wild beavers hunted in the Warmia and Mazury Region (Northeastern Poland). Contrary, Zalewski et al. [3] for thigh of adult beavers hunted in this same region obtained the following percentages 41.87, 29.26, 28.60% (20.38 and 7.71%) for total SFA, MUFA, PUFA (n-6 and n-3 PUFA). The observed differences in literature could be explained by seasonal variations in fatty acid composition or dissimilarities in diets related to various habitats of beavers. The monogastric species are amenable to changes in the fatty acid composition of intramuscular fat using different diets [38]. Beavers have highly developed adaptive skills and they can live in diverse habitats. A typical beaver habitat consists of wooded river banks, lagoons, and lakes with a relatively stable water level, streams and meadow communities [8]. They feed on nearly all plants that are available, including aquatic species and those growing on the shore. Most often, the animals forage within a distance of 20 m from the bank. The diet consists of more than 200 lakeside plants, as well as 100 tree species [39, 40]. Consequently, it is impossible to establish the influence of the diet on the lipid composition of meat in the studied species, and their characterization is based on the muscle lipid composition in their habitual environment. In present study the PUFA levels in the beavers comprised high proportions of PUFA, and these results are in agreement with the findings of Käkelä and Hyvärinen [41] and Zalewski et al. [4]. However, most of these studies were related to the fatty acid compositions of the adipose tissues.

In accordance with previous recommendations of WHO/FAO experts for preventing cardiovascular diseases, diets should provide an appropriate intake of PUFAs, i.e. between 6 and 10% of daily energy intake [42]. Moreover, they recommended that an optimal n-6 and n-3 PUFAs intake needed to be retained between 5–8 and 1–2% of daily energy intake, respectively. However, according to the latest available data there is no rational for a specific recommendation for n-6 to n-3 ratio, or LA to ALA ratio, if intakes of n-6 and n-3 fatty acids lie within the recommended amounts (essential LA 2.5–3% of energy and essential ALA >0.5% of energy) [32]. Taking into consideration above values the meat of beaver, despite the fact that contains a high amount of linoleic acid, as well a high n-6/n-3 PUFA ratio, meets the terms of FAO recommendations.

Even though the beavers are monogastric animals Käkelä et al. [38] found a level of trans-fatty acids averaged 4.5% in the beaver fat depot. The main trans-octadecenoic acid was vaccenic acid (trans-11-18:1) with 71% of the total trans-18:1 fatty acids and 3% of the total fatty acids of the adipose tissue of the beaver. Furthermore, the presence of trans isomers of octadecenoic acid C18:1 (t-OA) is quite natural in beavers, since they eat vegetable matter only and thus need certain 'microbiological support' to digest hard parts of trees [38]. Vegetable matter such as aspen and birch, which are important constituents of the beaver diet, does not contain t-OAs. Strazdina et al. [34] for *biceps femoris* of Latvian beaver found a higher content of elaidic acid averaged 3.30%. Contrary, in present investigation a sum of TFA in lipids from *semimembranosus* muscle was 2.25% and vaccenic acid (trans-11-18:1) averaged 1.17% of the total fatty acids. There are two sources of trans fats in the human diet. First refer to industrially generated trans fats called 'artificial' and the second ruminant trans fats (in meat and milk), described as 'natural'. Both of them are the result of a partial hydrogenation process and many 18:1 trans isomers are common to industrial and ruminant fats [43]. Weggemans et al. [44] revealed no differences in coronary heart disease (CHD) risk between total, ruminant, and industrial TFA for intakes up to 2.5 g/day. Nevertheless, on the one hand, TFA's are not synthesised by the human body and are not required in the diet [45]. On the other hand, dietary TFA's are provided by several fats and oils that are also important sources of essential fatty acids and other nutrients. Therefore, there is a limit to which the intake of TFA's can be lowered without compromising adequacy of intake of essential nutrients. EFSA [45] recommend that the intake of TFA's should be as low as is possible within the context of a nutritionally adequate diet. In opinion of FAO experts [46] in adults' diet the TFA intake from all sources should be no more than 1% of total energy.

Compared to present study Strazdina et al. [34] reported for *biceps femoris* of Latvian beaver a lower content of total cholesterol (49.51 mg 100 g^{-1}). In meat (from different commercial cuts) of other herbivorous rodents a concentration of cholesterol ranged from 17.7 to 33.6 mg 100 g^{-1} for wild adult capybara (males and females) [47] and from 32 mg 100 g^{-1} (adult males and females) to 40 mg 100 g^{-1} (young males and females) for wild nutria [48]. Contrary, Saadoun et al. [49] reported for thigh of farmed nutria aged 5 months a higher concentration of total cholesterol i.e. 70.1 mg 100 g^{-1} (males) and 72.7 mg 100 g^{-1} (females). Cholesterol is synthesised by the human body and is not required in the diet. Generally, experts previously recommend not exceeding a cholesterol intake of 300 mg per day in the adult population [42]. Because, most dietary cholesterol is obtained from foods which are also significant sources of dietary saturated fatty acids, experts of EFSA [45] decided not to propose a reference value for cholesterol beside the limitation on the intake of SFA.

Minerals

The contents of macro (K, Na, Mg and Ca) and micro (Fe, Zn, Cu and Mn) minerals in wild beaver *semimembranosus* are given in Table 5. The higher concentration of Na (676 mg kg^{-1}) while lower contents of K, Mg, Ca and Fe (3562, 218, 42 and 60 mg kg^{-1}) reported Korzeniowski et al. [33] for meat (from thigh, loin and tail) of farmed beavers aged between 7 and 19 years. Zalewski et al. [50] in *biceps femoris* from wild beaver males captured in Northeastern Poland found similar concentration of Zn and Cu (45 and 1.0 mg kg^{-1} fresh tissue) compared to beaver *semimembranosus* hunted in Lublin region (Central-East Poland).

Red meat is an important source of minerals in the human diet, supplying essential elements with high availability, particularly Fe and Zn [51]. The bioavailability of trace elements from red meat ranges from 30 to 45% for Cu, from 40 to 68% for Zn, from 55 to 95% for Mn and from 60 to 70% for Fe [52]. Iron in meat occurs mainly in its easily available haem form, which is bound with myoglobin and haemoglobin.

Beaver muscles store large quantities of oxygen which results from the specific environmental conditions of their live. It is reflected by a high concentration of total iron, ranging from 4.97 to 5.59 mg% [5] to 10.84 mg 100 g^{-1} [34]. Taking into consideration the proportion of heme Fe/100 g of total Fe (ranged between 70 and 83%) [52], the heme iron content in beaver meat in the present study (Table 1) was comparable to earlier Polish [5, 33] and Latvian [34] investigations. However, the high concentration of heme iron stated in this investigation could be related to incomplete exsanguination during treatment of culled animals.

Beaver diet contains high amounts of Cu and Zn [53]. The high zinc concentration in beaver muscles is related to high content of this element in tree leaves, bark, and cambium due to its (Zn^{+2}) intensive uptake by both the root system and the leaves [50].

Table 5 Mineral contents (mg kg^{-1}) of beaver *semimembranosus* (n = 6)

Mineral	Mean	SD	Min.	Max.
K	4029	137.6	3774	4159
Na	461.9	100.5	345.9	609.3
Mg	250.7	7.142	238.8	258.4
Ca	66.44	15.64	44.45	86.74
Fe	64.49	17.59	38.21	83.75
Zn	45.07	12.18	28.64	61.33
Cu	0.981	0.155	0.711	1.175
Mn	0.149	0.032	0.114	0.191

The European Union regulations refer to a product as a 'source' or 'high in' if a portion supplies at least 15% of the recommended daily intake or product must contain at least twice the significant amount of mineral/s [54, 55]. Using this nomenclature we can conclude that beaver meat for adults is primarily a rich source of Fe and Zn, as well a source of Cu.

A comparison of the nutritional profile of beaver muscle tissue in present study with lean meat of different domesticated animals from different nutrient databases [56–58] indicated a slight lower content of protein in chicken, but a considerably higher content of fat, and a consequently higher energy in all livestock sources (Table 6). The range of cholesterol content in beaver compares to beef and pork, while of all the meats concerned, chicken contains the highest amount of cholesterol. The total of PUFA is the predominant fatty acid in beaver meat, and the range is higher than all meat sources. MUFA are lower than all meats listed, as well as SFA are lower than all meats listed, except chicken. As an iron source, beaver is superior to all livestock meats reported. Moreover beaver provides more zinc and less sodium, especially with regard to chicken. The amino acids composition of beaver meat compared to beef round [56] is characterized by higher content of tryptophan (0.31 vs. 0.138 g 100 g^{-1}), but lower concentration of glycine (0.86 vs. 1.283 g 100 g^{-1}) and proline (0.75 vs. 1.004 g 100 g^{-1}). However, the content of other amino acids is very similar.

Conclusion

In summary, hunting beavers for consumption has been suggested as a tool for population management, and beaver consumption could occur in the near future in some countries of Central Europe [12, 15, 34].

The wild beavers were found as an excellent nutritional meat source with a desirable chemical composition and a low calorific value. The muscle protein was good in quality with a high value of NQI and well-balanced in amino acid composition as the percentage of indispensable acids averaged 45%. Moreover, the amino acid scores point to full compliance with the recommended amino acid requirements for adults and thus a high biological value of protein. This study indicates that the meat of beaver as a dietary source also reached complete fulfilment current health and dietary recommendations for low fat and low cholesterol diets. The lean beaver meat with predominant polyunsaturated fatty acids (49.08%) and acceptable the PUFA/SFA and the n-6/n-3 PUFA ratio values are considered as advantageous for human health and are coherent with diet recommendations. Owing to the fact that the content of the macro- and microelements in the meat of beavers was

Table 6 Comparison of nutritional profile of other meats as determined by the USDA [56], Fineli [57], and NutriData [58] food composition databases

Nutrient	Beef			Pork			Chicken		
	USDA 23,651	Fineli 718	NutriData 6310	USDA 10,010	Fineli 34,188	NutriData 6041	USDA 05080	Fineli 30,792	NutriData 6463
Protein (g 100 g^{-1})	21.1	21.7	22.0	20.5	21.5	20.0	19.2	19.6	20.9
Fat (g 100 g^{-1})	3.9	2.9	5.0	5.4	6.9	6.0	4.2	3.4	3.9
Energy (kJ 100 g^{-1})	504	475	559	548	621	562	482	461	500
Tryptophan (mg 100 g^{-1})	138	320	–	–	280	–	–	230	–
Cholesterol (mg 100 g^{-1})	57	52	63	68	52	58	91	83	105
Fatty acids (%)									
SFA	42.8	45.9	44.4	38.2	42.0	43.6	30.3	30.1	31.2
MUFA	51.0	39.2	48.9	49.9	48.0	49.1	41.5	37.1	40.6
PUFA	6.2	5.3	6.7	11.9	9.7	7.3	27.7	29.5	28.1
Minerals (mg 100 g^{-1})									
K	323	400	333	369	280	280	238	231	390
Na	54	41	58	55	42	49	96	86	90
Mg	22	25	22	25	20	20	23	24	24
Ca	18	7	6	6	7	7	10	10	7
Fe	1.77	3.10	2.20	1.01	0.60	0.60	0.78	1.04	0.80
Zn	3.89	3.80	3.80	2.27	1.80	1.60	1.76	1.91	1.70

high, it can be a valuable source of important elements for human beings, containing nutritionally beneficial amounts of minerals, particularly Fe (and its heme form), Zn, Mg, Cu and K, as well as of Na (due to its low level).

However, many pre-conceived notions as to its acceptability as a food source need to be overcome. The future acceptance of beaver as a meat source remains to be determined. In addition, further research should be conducted both to determine the content of nutrients in other muscles/meat cuts and to assess the effect of various culinary procedures on their preservation and bioavailability.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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